TACTICAL DISPLAY OF CZ PROPAGATION AREAS

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THESIS

TACTICAL DISPLAY
OF CZ PROPAGATION AREAS

by

David Blake Cahill

March 1977

Thesis Advisors: J. V. Sanders
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Tactical Display of CZ Propagation Areas

by

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ABSTRACT

The need for an enhanced display of the geographic distribution of convergence-zone propagation in a region of shallow and variable bottom topography is demonstrated. A preliminary display is generated utilizing point-by-point computer processing of the convergence-zone minimum depth requirements with a large bathymetric data base for a region north of the Azores. The trade-offs between the accuracy of the preliminary output and cost (computer time and space) are discussed.

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I. INTRODUCTION

A. GENERAL

The objective of this thesis is to demonstrate the use of computer techniques to provide an enhanced display of convergence-zone depth requirements for a geographic region where the transmission of sound by convergence path is limited by a variable bottom topography. The body of the thesis encompasses the theory of convergence-zone propagation, the oceanography of a region of interest, and the computer techniques utilized. In addition, the various trade-offs in computer accuracy, presentation of display, and cost (computer time and space) are discussed.

B. REGION OF INTEREST

The particular geographic region of interest is limited to that area north of the Azores archipelago as depicted in Figure 1. It is a region dominated by the greatest mountain range in the world, the Mid-Atlantic Ridge, which rises to less than 1500 fathoms below the surface in many areas. In this region, the Mid-Atlantic Ridge is characterized by a wide, deep rift running north to south, and fracture zones which appear as transverse cuts or gaps through the ridge. It is an area of high seismic activity

40 W
30 W
20 W
0 W
ICELAND
Reykjavik
SURTSEY
REYKJANES RIDGE
-7800
-2160
FAEROE ISLANDS
-528
LOUSY BANK
60 N
-6450
-594
-1740 (14260)
ROCKALL
-9510
-780
BRITISH ISLES
London
50 N
-308 (15694)
-15420
BISCAY ABYSSAL PLAIN
-4760
-4500 (11500)
RIFT VALLEY
-15400
-336 (15664)
-17280
-17700
-15300
40 N
IBERIAN PENINSULA
AZORES
Pico
-7615 (23615)
Lisbon
-16880
FRACTURE ZONE
-4500
AMPERE SEAMOUNT
-132 (15868)
-870
-12000
-960 (15040)
-6106
MADEIRA ISLANDS
Jebel Toubkal 13665
ATLAS MOUN
-17820
-15000
-1470 (14530)
-12600
-12198
CANARY
30 N

Figure 1.

and of marked variability in water depth. The shallowness of the water in this region has a severe effect on the transmission of sound by convergence path.

C. DISCUSSION OF THE PROBLEM

In this region, ASW search areas can be characterized by their great size. To search such large areas with direct path tactics is obviously expensive, both in sonobuoy expenditures and search effort. It is evident that employment of convergence-zone (CZ) tactics is highly desirable when investigating such large areas. Due to the sound speed profile (SSP) and bottom topography, CZ propagation is not always feasible throughout this region. However, there may be many sub-areas where the bottom depth will allow the use of CZ search tactics, thereby providing the capability to search more effectively.

D. PRESENT CZ FORECASTING PROCEDURES

Currently, the weekly Fleet Numerical Weather Central (FNWC) transmission-loss forecast (ASRAPS) is utilized to determine whether CZ propagation is expected for an area. In addition, this forecast provides the ASW planner with the expected minimum depth required for CZ propagation. This minimum depth is then compared to a bottom contour chart and, if depth excess is available, appropriate CZ

tactics may be employed. There are several shortcomings in this procedure, as outlined below:

1. Size of Prediction Areas

In general, ASRAPS prediction areas or domains are relatively large. For example, FNWC models the region under discussion by 13 domains, of which 6 domains cover approximately 80 per cent of the region's total area. The domains are determined mainly by the type of bottom sediment, bottom topography, and the type of water mass. While the size of an individual domain is relatively large, it is interesting to note that a prediction for a domain is, in reality, a single point forecast which is considered to be representative of the entire domain. In a previous study (Ref. 1) based on FNWC data, it was determined that the predicted CZ minimum depth requirement varied by as much as 300 fathoms between two points located in adjacent domains only 180 nm. apart. Thus the depth required at one end of a CZ pattern may be significantly different from that which is required at the other end. In addition, when operating at a boundary between domains, the ASW planner is forced to extrapolate a CZ depth requirement from two forecasts, a procedure which may be inaccurate.

2. Bottom Depth

The ASRAPS model is based on a mean bottom depth and assumes a flat, parallel bottom throughout the entire domain. In regions near the Mid-Atlantic Ridge where the bottom topography is extremely variable, a "mean deep depth" is employed. By definition, 20 per cent of the area's bottom is deeper than the "mean deep depth." Consequently, it is possible for an ASW planner to find that depth excess is not predicted for a domain, while there may be localized areas within the domain where CZ propagation is feasible. Unfortunately, this may lead the ASW planner to select direct path tactics when a CZ tactic may be employed more effectively.

3. Bottom Topography

Existing bottom topography and contour charts are detailed and frequently utilized in ASW planning in this region. While highly advantageous to the surface officer in determining whether his sonar echoes are from sea mounts, they compound the tactical decision for the optimal placement and orientation of CZ patterns. The ASW planner must visually decide where CZ propagation is available, often interpolating between contour intervals. It is a slow, tedious process, done by hand and eye, and is highly susceptible to error. An error at this point in the decision

process degrades the CZ pattern integrity or reduces the search area coverage and may render the tactic useless.

E. PROPOSED SOLUTION

During most ASW tactical situations, the ability of the ASW planner to make rapid decisions is regarded as a definite asset. Assigned search areas in this region change rapidly due to the updating of information and they expand and move due to the elapsed time since the last contact on the target. In addition, the ASW planner is confronted with a myriad of details involved with the briefing and debriefing of flight crews, often in rapid succession. For optimum effectiveness, the ASW planner must be provided CZ tactical information in a timely and concise manner.

Modeling of bottom topography, coupled to point-by-point rather than domain CZ depth requirements, can be utilized to provide an enhanced CZ tactical display and reduce the errors made by the ASW planner. Such procedures reduce the CZ tactical display to a resolved bottom topography chart showing where CZ propagation is and is not predicted. It is anticipated that such a chart could be reproduced by facsimile and transmitted as part of the weekly ASRAPS forecast. Thus the decision of where the CZ is geographically predicted on the Mid-Atlantic Ridge would be less of a problem for the ASW planner.

II. ACOUSTICS

A. GENERAL

The enhanced intensity in the convergence zone has been well documented by theoretical and experimental work since the early 1950's. Hale and Urick presented excellent discussions of both shallow and deep source CZ propagation in references 2 and 3 respectively. Indeed, CZ propagation has become so well known that it is a standard topic of present underwater acoustic textbooks. In this chapter, the theory of CZ propagation is briefly summarized with emphasis on the variables that determine the depth required for such propagation.

B. CZ CHARACTERISTICS

A convergence zone is an annulus surrounding a non-directional sound source in which the sound intensity is significantly higher than would be expected from spherical divergence and absorption losses. Convergence zones usually occur at a range of 25-35 miles from the source and the width of the annulus is approximately ten per cent of that range. The exact values of the range and width depend on the details of the sound speed profile (SSP). If the SSP is known, it is then possible to calculate the range and

width of the CZ and the depth required for this propagation to take place. While there are several theoretical models available for describing or predicting CZ propagation, ray theory is perhaps the easiest to visualize and discuss. The computation of such ray paths is simplified by the utilization of Snell's Law of Refraction which states:

$$c/\cos\theta = \text{a CONST (along a ray)}$$

where c is the speed of sound and θ is the angle of inclination of the ray (see Fig. 2). As a consequence of Snell's law, a ray will always bend toward the region of lower sound speed. Thus, for the typical deep-water SSP depicted, a sound ray generated at the surface will curve upwards until it reaches depth "a" (the maximum near-surface speed), then it curves downward until depth "b" (the minimum speed), and then upwards, eventually returning to the surface if the ocean is deep enough to allow θ to reach zero (at depth "c"). The ray "1" that crosses depth "a" with θ equal to zero is particularly important, for it is this ray which defines the convergence zone. (This will not be shown, for proof see Ref. 4.)

It is easily seen from Snell's law that the depth "c" at which the ray becomes horizontal and turns back toward the surface is that depth where the speed of sound is equal

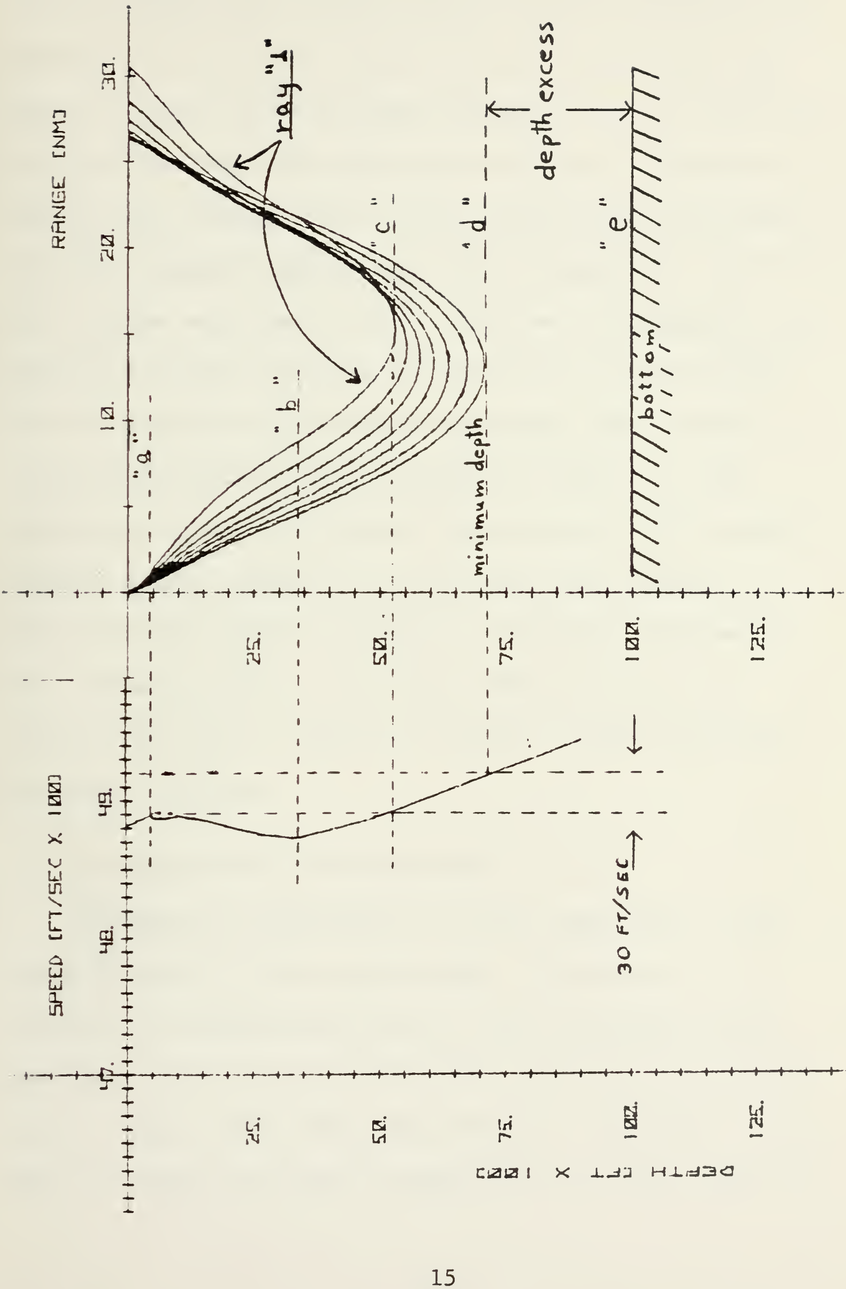

RANGE [NM]
10.
20.
30.
SPEED [FT/SEC X 100]
47.
48.
49.
DEPTH [FT X 100]
25.
50.
75.
100.
125.
ray "1"
depth excess
"a"
"b"
"c"
"d"
"e"
minimum depth
bottom
30 FT/SEC

Figure 2.

to the maximum near-surface speed. For CZ propagation to exist, it is necessary for the ocean to be at least this deep. However, for sufficient energy to arrive at the CZ, rays steeper than that mentioned above must be allowed to reach their turning point. This requires that the actual depth be somewhat greater than that necessary for ray "1." The minimum depth required for efficient CZ propagation is defined by Fleet Numerical Weather Central as that depth where the sound speed exceeds the maximum near-surface speed by 30 ft/sec (refer to depth "d," Fig. 2). The difference between the actual bottom depth, "e," and this minimum depth required is called the "depth excess" by Fleet Numerical Weather Central. A positive depth excess will normally allow a sufficient number of rays to be focused into the CZ annulus to provide a useful increase in sound intensity.

C. VARIABILITY OF CZ MINIMUM DEPTH

A feature of considerable tactical importance is the time stability of the minimum depth. Variations in the value of the minimum depth due to the fluctuating oceanographic properties frequently limit the accuracy of prediction. However, the convergence zones are remarkably stable. While seasonal and diurnal changes in the minimum depth do

occur, knowledge of the sound speed in the mixed layer will allow reasonable estimates. This is due to the fact that the sound speed at depth changes slowly from season to season and is only weakly affected by the processes which occur near the surface on a daily basis. Thus knowledge of the seasonal or weekly changes in the sound speed in the upper 150 fathoms of the ocean makes calculation of the depth excess reasonably accurate. As an example, a change in the near-surface water temperature from 52° to 50°F would reduce the maximum near-surface sound speed by approximately 20 ft/sec. Such a change produces a reduction in the minimum CZ depth required of approximately 200 fathoms. Note that these temperature changes are not unreasonable during the winter months for the region discussed.

III. OCEANOGRAPHY

A. GENERAL

The oceanography of the region is complicated by the influx of warm, highly saline water from the Mediterranean which spills into the Atlantic through the Strait of Gibraltar. This influx diffuses northward and westward from the Strait and mixes with the typical water mass of the region, the North Atlantic Central Water. The deep and bottom waters of the region are remarkably uniform in character on both sides of the Mid-Atlantic Ridge, which does not act as a barrier separating the region into different water masses (see Ref. 5). However, the topography of the ridge does apparently affect the distribution of salinity and temperature in the near-surface and intermediate waters of the region (Ref. 6). The oceanographic features and processes discussed below are causal factors of the variability of CZ minimum depth found throughout the region.

B. THE CENTRAL NORTH ATLANTIC FRONT

Primarily caused by the lower branch of the North Atlantic Current, an oceanic front, called the Central North Atlantic Front (CNAF) is formed in the region (see Ref. 7). The CNAF is well defined at the surface during the winter season and

the deep front (110 fm) generally coincides with the position of the surface front during this period. At times the actual position and intensity of the front may be obscured due to local heating of the surface or intensive mixing caused by storms. However, the position of the CNAF plays a major role in determining the depth excess available for CZ propagation in this region. Figure 3 shows the mean position of the CNAF varying by several hundred miles during the winter season of 1968. When the front is displaced southward, colder near-surface waters flow into the northern part of the region. Consequently, the minimum CZ depth requirement is reduced.

C. STORMS

While detailed before and after analysis of the effect of storms on the oceanographic conditions of the region could not be found in the literature, storms are another major factor which govern the CZ depth requirement in this region. Strong atmospheric cold fronts proceeding easterly across the region during the winter months cause intense storms and high winds. The associated Ekman transport (see Ref. 7) moves colder near-surface waters into the region from the north and west. The strong, cold winds cause intensive mixing and a further cooling of the near-surface

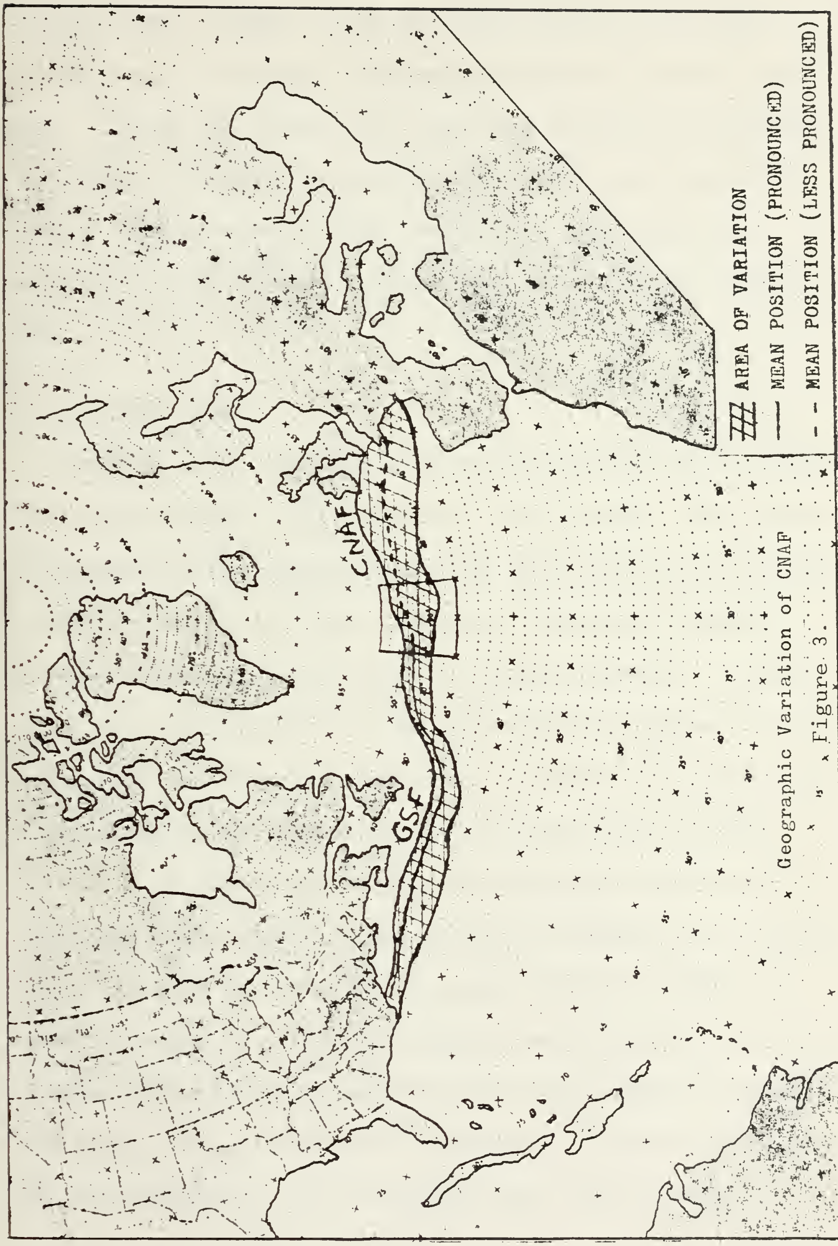


Figure 3. Geographic Variation of CNAF

water. Thus, storms reduce the sound speed of the near-surface water, thereby reducing the minimum CZ depth requirement. While the effects of storms are generally considered localized, it should be pointed out that these atmospheric fronts usually move through the entire region and the associated high winds and heavy seas may exist for several days.

D. OTHER FACTORS

Several more localized factors also influence the temperature and salinity distributions in the region. The bottom topography of the ridge interacting with currents may create eddies or pockets of water similar to the way in which terrestrial mountains interact with air currents. A recent study (Ref. 6) describes such an interaction between bottom topography and currents resulting in pockets of cooler water forming and being surrounded by the warmer water of the current. In addition, warming of the bottom water on a localized basis either by conduction or venting is a distinct possibility in the region due to its frequent seismic and volcanic activity. The distribution and intensity of such warming throughout the region is not fully known; however, reference 9 reports one such apparent localized warming of the bottom water. It is suspected that such warming is

confined to the rift valley and fracture zones where seismic and volcanic activity is strongest.

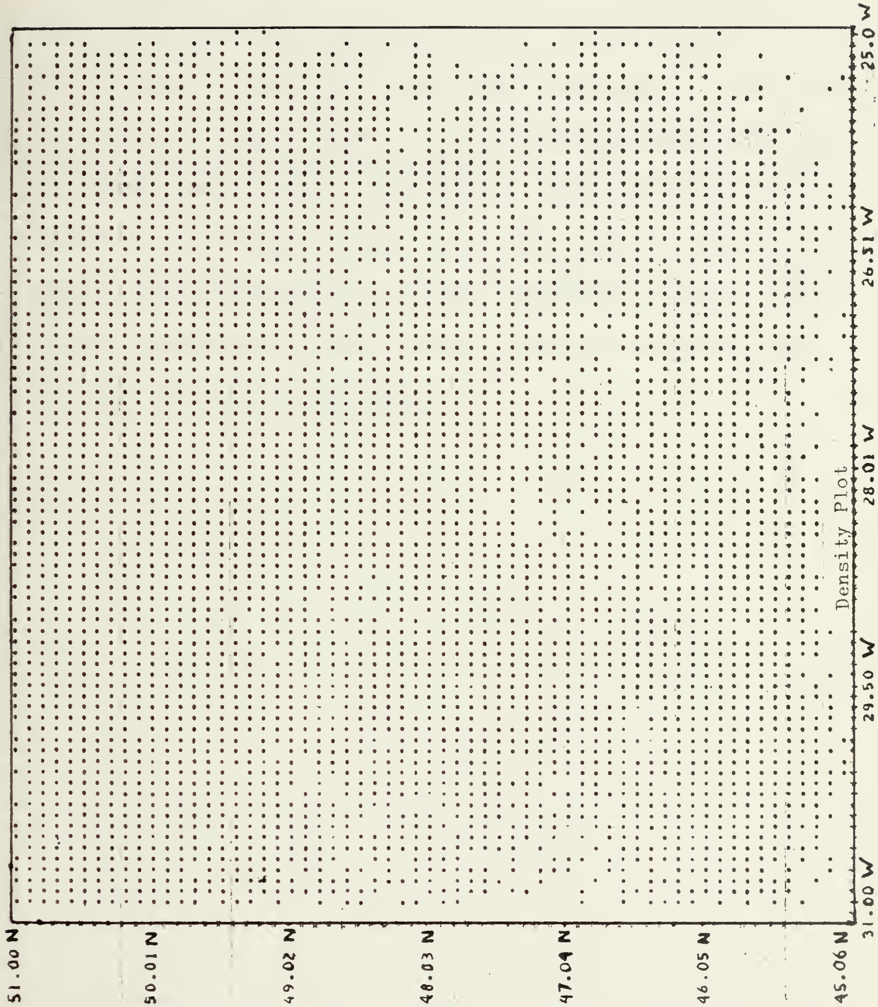
E. OCEANOGRAPHIC DATA

1. Bottom Topography

The 18,000 reported depths utilized in this thesis were recorded with the fathometer set for a sound speed of 800 fm per sec. The bathymetric data was obtained from the Defense Mapping Agency and was restricted to less than 2500 fathoms due to the shallowness of the minimum CZ depth requirement in the region. A density plot (Fig. 4) shows the data to be uniformly distributed geographically. It is assumed that the clear areas of the density plot represent areas where the reported depths were greater than 2500 fm; however, a small possibility exists that there may be unreported depths of less than 2500 fathoms in these areas. Since the depths were recorded at 800 fm per sec, sound speed corrections to the reported depths were made utilizing linear approximations derived from reference 10.

2. CZ Minimum Depth Requirements

Predicted CZ minimum depth requirements for the month of February 1977 were obtained from Fleet Numerical Weather Center utilizing historical data and the standard ASRAPS model. The 36 geographic locations and the predicted CZ



Density Plot

Figure 4.

minimum depths are listed in Table I. The table shows wide variation of the CZ minimum depth requirement in a north-south direction throughout the area. In the northern portion of the region, significant east-west variation of the depth requirement is also shown. The CZ minimum depths reported, by themselves, support the need for point-by-point predictions in this region. When the variability of the resultant depth excess caused by the rugged topography of the region is also considered, then the need for a resolved CZ depth chart is clearly demonstrated.

TABLE I

Prediction points and minimum CZ depths (in fathoms)

Lat: 50.5 N

Long:	30.5 W	29.5 W	28.5 W	27.5 W	26.5 W	25.5 W
Depth:	922	951	979	1017	1071	1083

Lat: 49.5 N

Long:	30.5 W	29.5 W	28.5 W	27.5 W	26.5 W	25.5 W
Depth:	1033	1061	1115	1131	1135	1131

Lat: 48.5 N

Long:	30.5 W	29.5 W	28.5 W	27.5 W	26.5 W	25.5 W
Depth:	1112	1148	1162	1171	1190	1184

Lat: 47.5 N

Long:	30.5 W	29.5 W	28.5 W	27.5 W	26.5 W	25.5 W
Depth:	1181	1193	1200	1217	1221	1216

Lat: 46.5 N

Long:	30.5 W	29.5 W	28.5 W	27.5 W	26.5 W	25.5 W
Depth:	1235	1257	1257	1254	1268	1259

Lat: 45.5 N

Long:	30.5 W	29.5 W	28.5 W	27.5 W	26.5 W	25.5 W
Depth:	1308	1313	1306	1309	1298	1297

IV. COMPUTER PROCESSING

A. GENERAL

The data was processed on the IBM 360/67 computer and associated Calcomp 765 plotter of the W. R. Church Computer Center at the Naval Postgraduate School. This processing involved converting the original bathymetric data to a usable format, comparison of the CZ minimum depths required to the depths available, scaling of the positional data for Mercator projection, and plotting the positions where CZ propagation is not predicted due to reported bottom topography. In order to scale the output plot for comparison to the appropriate NAC-xx series bottom contour chart, only a subarea of the region discussed was selected for processing. The computer routines utilized are not reproduced herein but are available on request from Assoc. Prof. G. Brown, Code 55Bw, NPS.

B. DATA FORMAT

The bathymetric data received was contained on a seven-track, 800 bpi magnetic tape which was converted to a nine-track, 1600 bpi tape compatible with the IBM 360. This conversion was complicated by the fact that the fixed block length of the original data was not a multiple of the

individual record length. In addition, each individual record of four data points was followed by a ten character code which had to be deleted. The combination of mixed record and block length with the interspersed coding required the assistance of a professional programmer for converting the original tape. A trial-and-error method had to be employed which eventually resulted in a successful conversion, however, much time and effort was spent in overcoming this difficulty. The positional data was reported in degrees, minutes, and fractions of seconds and was converted to degrees and hundredths of degrees in order to reduce core storage requirements.

C. OUTPUT

The Mercator scaling of the output chart (Fig. 5) was accomplished by formulae developed from reference 11 and the plot was generated by utilizing a standard plotting package (Ref. 12). The output chart shows the positions within the subarea where the reported depth available is less than or equal to the predicted CZ minimum depth required to support CZ propagation based on the FNWC historical data for February 1977. Thus the clear areas of the output chart represent areas where CZ tactics may be employed and the ASW planner can readily decide where to geographically locate the CZ

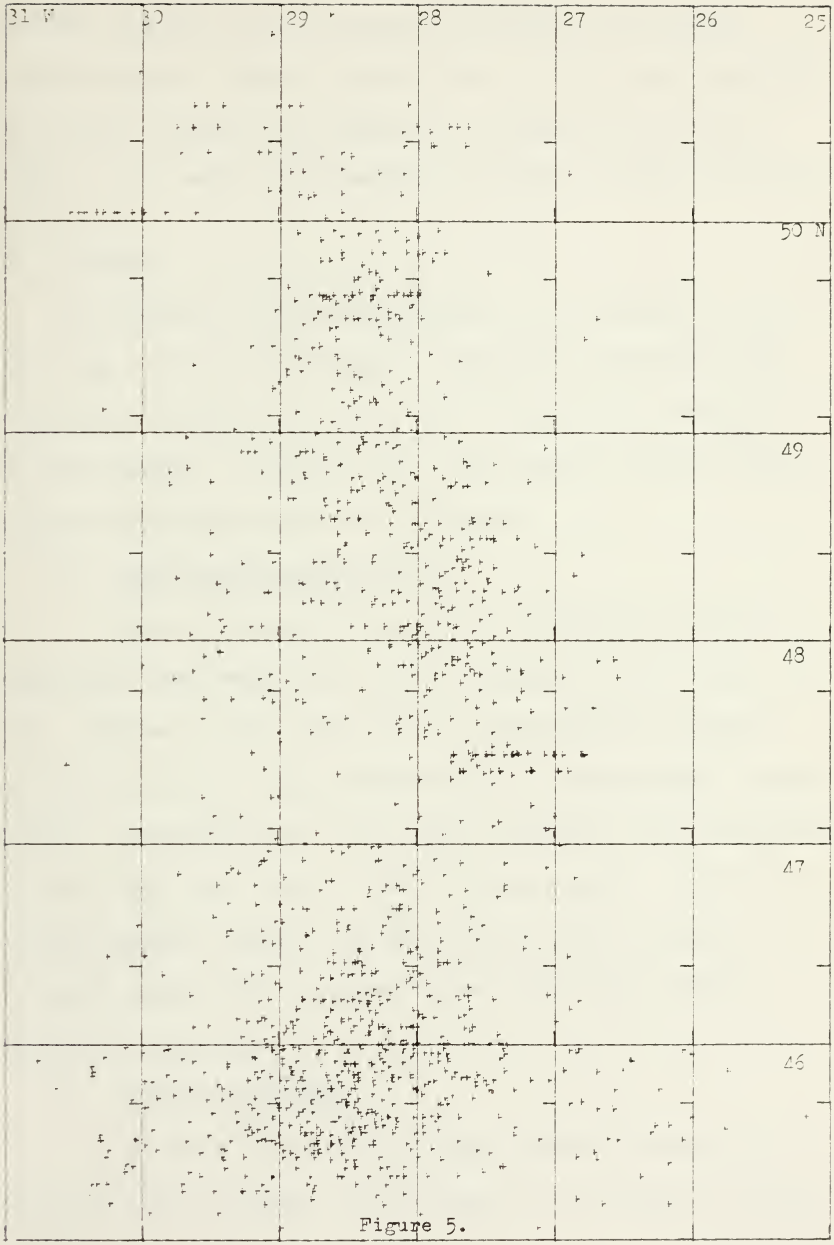


Figure 5.

pattern and what type of pattern to employ for optimum effectiveness. Such an output chart could be used directly by the ASW planner and requires no interpolation by him either in CZ depth requirements or between contour intervals.

D. ACCURACY

The accuracy of the output chart is a function of both the input data and the computer operations performed upon the data. In order for the output to be of full value to the ASW planner, errors in the input data or caused by the computer operations must be minimized.

1. Depth Requirement Errors

The use of historical data to generate the CZ minimum depth requirement can lead to serious errors in the output. However, these errors can be significantly reduced by the use of real-time observations of oceanographic parameters. Procedures for the rapid collection and transmission of such real-time data to FNWC currently exist. Such procedures greatly enhance the ability of FNWC to provide accurate predictions of existing and near-term oceanic acoustic conditions.

2. Bottom Topography

Analysis of the output chart reveals several sets of suspicious soundings which appear to be linearly aligned

in the east-west direction and could not be confirmed with a bottom contour chart. It was not determined whether these probable errors were caused during the initial tape conversion or were errors made when the original soundings were taken.

3. Computer Operations

Point-by-point processing required the utilization of an interpolation scheme to generate the CZ depth required for the areas between the original 36 data points. Due to the variability of the original depths, errors were induced by this interpolation. To determine the severity of these errors, the interpolation scheme was utilized to generate the CZ depth requirements for the original data positions. The worst approximations at these points were 23 fathoms too shallow and 25 fathoms too deep (about two per cent error). However, the mean error of the interpolation scheme was only 9.39 fathoms with a standard deviation of 6.93 fathoms (less than one per cent error). Thus, it is 75 per cent probable that any particular depth interpolation error is less than $\pm$ 14 fathoms by Tchebychev's inequality (95 per cent by Normal assumption). Errors induced by the scaling of the plot and the depth corrections to the original bathymetric data were not determined but are considered minimal.

E. TRADE-OFFS

While the use of computers is generally considered a cost-reducing technique in data processing, the desire for exact solutions can easily increase the cost of such processing by increasing the computer time and core storage required for an acceptable solution. Several examples of the trade-offs made in this thesis between cost and accuracy have already been noted. For instance, the use of approximate linear interpolations rather than exact solutions and the reduction in core storage achieved by alteration of the original bathymetric data format. Both of these trade-offs resulted in a reduced cost to produce the final output by considerably lowering the computer time and storage required, while inducing an error of less than one per cent. A third trade-off is apparent when one considers the ideal output format desired by the ASW planner. A chart with a contour line drawn at the depth where the bottom intercepts the CZ minimum depth requirement may be more useful to the ASW planner than the output shown as Figure 5. However the time required to generate such a contour plot is considerably greater than the 49 seconds of computer time and ten minutes of plotting time required for this output format. In addition, contouring routines can severely affect the accuracy of the final output due to interpolations between the data

points to generate a smooth curve. This is especially important to consider in this case where there is such extreme variability in the bathymetry of the region.

V. CONCLUSION AND RECOMMENDATIONS

With the decreasing allowances of sonobuoys and flight hours available for ASW search due to current fiscal restraint, it is imperative that every effort be made to exploit CZ sound propagation to the fullest extent. In order to effectively accomplish this in the region discussed, the need for an enhanced CZ display is clearly demonstrated. Indeed, the need for such an enhanced display is not restricted to this region alone, but could be demonstrated in any of the world oceans where the bottom topography interferes with CZ sound propagation.

Due to the large bathymetric data base employed in this thesis, the IBM 360/67 computer was chosen for processing the data. However, by reducing the data base to reported depths of less than 2000 fathoms and blocking the data into 1° squares, sequential block processing (with point-by-point processing within each square) could be accomplished utilizing computers with much less core storage. Thus the ASW planner could use a "minicomputer" or desk-top calculator such as the HP-9830 to locally generate an enhanced CZ display and eliminate the need for transmission of a facsimile copy of the output. Given current observations of the near surface

sound speeds and an historical deep-water sound speed profile, the local user could also generate real-time predictions. While the routines employed are specific for the area processed, they can readily be expanded or modified to a more general nature. In particular, the addition of a subroutine to automatically interpolate the CZ depth requirements at any point between the input CZ depths would prove invaluable.

The format of the output shown here is not the final solution to the problem, but is a step in the right direction. An alternative would be to code the plot with several symbols which would indicate various amounts of depth excess. Such an output would show where CZ propagation is and is not predicted and a transition region.

In summary, the ideas presented here are but one method of improving ASW search effectiveness in the region discussed and can be applied to other regions as well. The need for such improvement has been clearly shown and it is hoped that further research will eventually result in an enhanced CZ display for the ASW planner.

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